EVALUATION OF THE EFFECTS OF A HIGHWAY IMPROVEMENT PROJECT ON KEY DEER

A Thesis

by

ANTHONY WAYNE BRADEN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2005

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Roel R. Lopez
Committee Members,	Nova J. Silvy
	Donald S. Davis
Head of Department,	Robert D. Brown

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ABSTRACT

Evaluation of the Effects of a Highway Improvement Project on Key Deer.

(August 2005)

Anthony Wayne Braden, B.S., Texas Tech University

Chair of Advisory Committee: Dr. Roel Lopez

Deer-vehicle collisions (DVCs) along a 5.6-km segment of United States Highway 1 (US 1) on Big Pine Key (BPK), Florida responsible for approximately 26% of endangered Florida Key deer (*Odocoileus virginianus clavium*) annual mortalities. The Florida Department of Transportation (FDOT) constructed a 2.6-km long system of fencing, 2 underpasses, and 4 experimental deer guards to address DVCs along a portion of the US 1 roadway in 2001–2002.

I evaluated the effectiveness of the project in reducing Key deer mortality by comparing (1) survival of radio-collared deer, (2) deer-vehicle collisions on US 1, and (3) determining the ability of deer to access the fenced segment. I found no significant difference in male or female survival. Key deer-vehicle collisions were reduced by 83–92% inside the fenced segment. However, overall US 1 Key deer-vehicle collisions did not change. Key deer entry into the fenced segment was minimized to 8 deer during the first-year resulting in 2 deer mortalities.

I also assessed the potential impacts of the US 1 corridor project to Key deer movements by comparing (1) radio-collared Key deer annual ranges (2) radio-collared deer corridor movements, and (3) assessing Key deer underpass and corridor use. Female and male ranges and core areas did not change ($P > 0.05$). Deer movements within the US 1 corridor were comparable pre- (6 of 23 radio-collared deer crossed the corridor) and post-project (4 of 16). Infrared-triggered camera data indicate underpass movements increased over time. Collectively, post-project telemetry and camera data indicates US 1 highway improvements have not restricted Key deer movements.

Hourly Key deer movement and US 1 traffic patterns were compared to annual US 1 DVCs. Hourly deer movements showed a positive correlation ($P = 0.012$, $r = 0.505$) to hourly DVCs for the full circadian period. Hourly US 1 traffic showed a significant positive relationship (P = 0.012, $r = 0.787$) with DVCs only during the night period. Evaluation of hourly deer movements and hourly traffic volume on US 1 found hourly DVCs to be the result of a combination between both variables.

DEDICATION

To my Mom and Dad

ACKNOWLEDGMENTS

I would like to thank my committee members, Roel Lopez, Nova Silvy, and Donald Davis, for their always positive guidance and support during the research and writing of this thesis. The patience and understanding that they and Dr. W. Grant have shown me can not be overstated. I thank Catherine Owen and Bret Collier for their constructive comments and insight on portions of this thesis.

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This research would not have been possible without the fieldwork assistance of Clay Roberts, Melanie Howey, Kyle Melton, Israel Parker, Nils Peterson, and Craig Faulhaber. I express my appreciation to Amy Snelgrove and Dale Kubenka for their assistance with reprojecting GPS locations for further analysis. Finally, I would like to thank the fellow graduate students, roommates, family, and friends who provided invaluable moral support during this project.

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CHAPTER I

INTRODUCTION

BACKGROUND

Florida Key deer (*Odocoileus virginianus clavium)* occupy 20–25 islands in the Lower Florida Keys, with approximately 65% (453–517 deer in 2000) of the overall population found on Big Pine Key (BPK, [2,548 ha]; Lopez et al. 2004*a*). Since the 1960s, deer-vehicle collisions (DVCs) have been the single largest Key deer mortality factor accounting for >50% (60–81 DVCs in 1996–2000) of annual losses (Silvy 1975, Lopez et al. 2003*b*). In 2000, 69 DVCs were recorded on BPK (United States Fish and Wildlife Service [USFWS], unpublished data). Additionally, over half (35–50 DVCs in 1996–2000) the DVCs occur along United States Highway 1 (US 1) on BPK; a 5.6-km segment of roadway which bisects the southern end of BPK. Due to the high occurrences of Key deer-vehicle collisions along this road segment, USFWS and Florida Department of Transportation (FDOT) biologists have attempted to address DVCs on US 1.

In 1994, the Key Deer-Motorist Conflict Study was initiated by FDOT to evaluate alternatives for reducing DVCs along the US 1 corridor (Calvo 1996). Furthermore, in 1995 the US 1 traffic level of service on BPK (i.e., ability to evacuate residents during a hurricane) was found to be inadequate (Lopez et al. 2003*a*). The 2 objectives of the Key Deer-Motorist Conflict Study were to (1) decrease DVCs, and (2) improve US 1 traffic flow.

The format and style of this thesis follows Journal of Wildlife Management.

During the evaluation of alternatives to reduce DVCs on US 1, deer movements also were of concern because the proposed US 1 corridor-project area was a narrow (<150 m) natural corridor and the sole land connection between north and south BPK. Harveson et al. (2004) reported that deer on north BPK served as a “source” population for deer populations in south BPK, emphasizing the importance of understanding deer movements within the proposed project area.

Final Key Deer-Motorist Conflict study recommendations included (1) construction of barriers (fences and deer guards) with 2 wildlife crossings (underpasses) along an undeveloped segment of US 1 on BPK, and (2) an extra northbound lane through the developed segment of US 1 (hereafter US 1 corridor project; Calvo 1996). A portion of US 1, the developed “business” segment which includes the extra traffic lane, was not fenced due to potential economic losses (i.e., restricted business access in an area with a tourist-based economy; Calvo 1996, Lopez et al. 2003*a*).

In 2002, construction of the 2.6-km fenced segment, 2 underpasses, 4 experimental deer guards (Peterson et al. 2003), and the extra 1.4-km traffic lane were completed. Based on the project design, USFWS biologists estimated (1) a 66% reduction in deer-vehicle collisions along the fenced segment due to deer entering the fenced segment and deer-vehicle collisions at fence ends, and (2) a 50% increase in deer-vehicle collisions in the unfenced segment as a result of additional traffic associated with the extra lane (Key Deer Habitat Conservation Plan 2005, under review). However, with no similar Key deer road improvement projects in existence, there was no information on which to base these estimates. There also was no information available on how Key deer ranges or movements would be effected by the US 1 corridor project or whether Key deer would use the underpasses.

STUDY AREA

US 1 is a 2-lane highway that links the Keys to the mainland with an estimated annual average daily traffic volume of approximately 18,000 vehicles/day (Fig. 1.1; FDOT data, Monroe County, 2004). US 1 bisects the southern half of BPK with maximum speed limits of 72 km/hr during the day and 56 km/hr at night. Vegetation near sea level and in tidal areas on BPK is comprised of black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*) forests. With increasing elevation, maritime zones transition into hardwood (e.g., gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipula*] and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) upland forests with vegetation intolerant of salt water (Dickson 1955, Folk 1991, Lopez et al. 2004*b*).

OBJECTIVES

The objectives of my study were to:

1. Determine the effects of the US 1 corridor project on Key deer mortality (Chapter II).
2. Evaluate Key deer underpass use and corridor movements following completion of the US 1 corridor project (Chapter III).
3. Determine how Key deer movements and US 1 traffic flow relate to US 1 Key deer-vehicle collisions (Chapter IV).

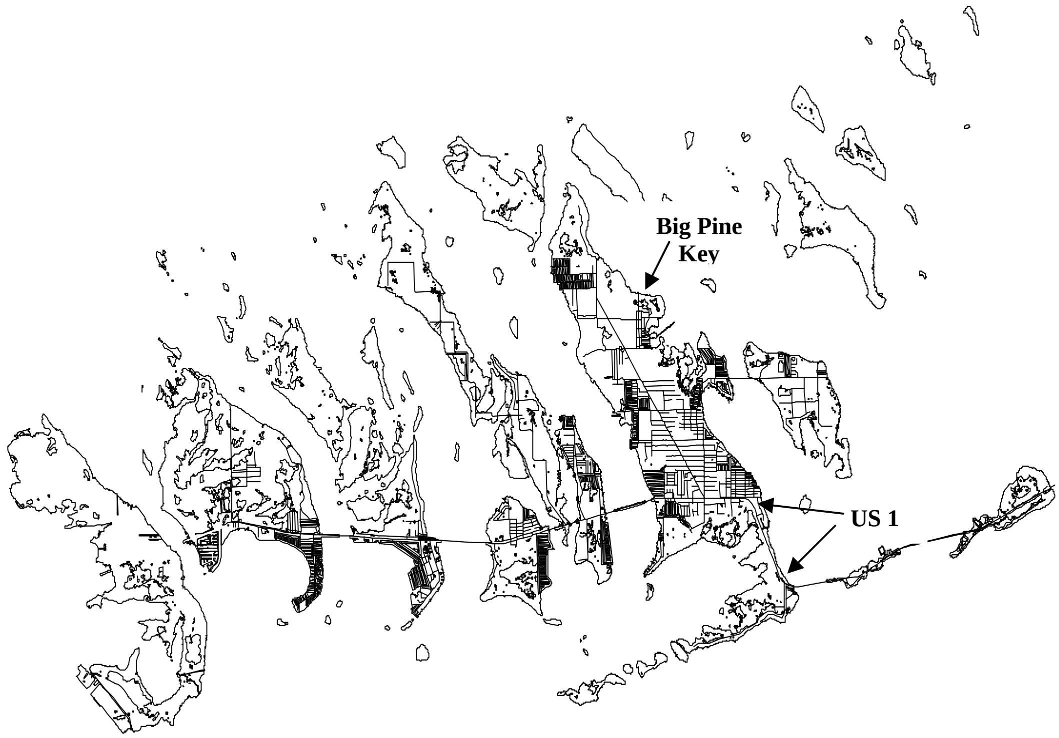

Figure 1.1. Location of US 1 on Big Pine Key within the range of the endangered Florida Key deer, Monroe County, Florida.

CHAPTER II

EVALUATION OF FENCING, UNDERPASSES, AND DEER GUARDS IN REDUCING KEY DEER MORTALITY

SYNOPSIS

Deer-vehicle collisions on a 5.6-km segment of United States Highway 1 (US 1) on Big Pine Key, Florida were responsible for approximately 26% of annual mortality of the endangered Florida Key deer (*Odocoileus virginianus clavium*). The Florida Department of Transportation has attempted to address deer-vehicle collisions along this road segment by excluding deer from a portion of US 1. A 2.6-km long system of 2.4-m fencing, 2 underpasses, and 4 experimental deer guards was completed on approximately 46% of US 1 on Big Pine Key in 2002. Key deer-vehicle collisions were reduced by 83–92% inside the fenced segment; however, overall US 1 Key deer-vehicle collisions (including unfenced portion) did not change following the addition of the extra lane of traffic needed for hurricane evacuation. Experimental deer guards, fencing, and underpasses minimized Key deer entry into the project area to 8 deer during the first year, resulting in 2 deer mortalities (1 deer-vehicle collision, 1 severe-removal injury). With the US 1 highway improvement project shown to effectively reduce Key deer-vehicle collisions, I recommend that experimental deer guards in combination with fencing (and underpasses when applicable) be used in other suburban and urban areas where traffic safety and deer access are an issue.

INTRODUCTION

Deer-vehicle collisions have increased in the United States, Canada, and Europe in the last several years (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Putman 1997, Forman et al. 2003). In the United States, 720,000–1.5 million estimated deer-vehicle collisions occur each year, resulting in approximately 29,000 human injuries and 211 human fatalities (Conover et al. 1995, Forman et al. 2003). In addition to human dangers associated with deer-vehicle collisions, approximately 92% of deer-vehicle collisions result in deer mortality (Allen and McCullough 1976). Reduction of deer-vehicle collisions will become increasingly important with continued suburban sprawl (McShea et al. 1997, DeNicola et al. 2000), increased road densities, and higher traffic coinciding with wildlife activity (Forman et al. 2003).

Florida Key deer (*Odocoileus virginianus clavium*) are the smallest subspecies of white-tailed deer in the United States (Hardin et al. 1984), with an average shoulder height between 61–81 cm and average weights of 29 kg and 38 kg for females and males respectively (Lopez 2001). Key deer occupy 20–25 islands in the Lower Florida Keys, with approximately 65% (453–517 deer in 2000) of the overall population found on Big Pine Key (BPK, [2,548 ha]; Lopez et al. 2004*a*). Since the 1960s, deer-vehicle collisions have been the single largest Key deer mortality factor accounting for >50% of annual losses (Silvy 1975, Lopez et al. 2003*b*). Sixty-nine Key deer-vehicle collisions were recorded on BPK in 2000 (United States Fish and Wildlife Service [USFWS], unpublished data). USFWS and Florida Department of Transportation (FDOT) biologists have attempted to address deer-vehicle collisions on United States Highway 1

(US 1) which bisects BPK (Fig. 2.1). In 1994, the Key Deer-Motorist Conflict Study was initiated by FDOT to evaluate alternatives for reducing deer-vehicle collisions along the US 1 corridor (Calvo 1996). Furthermore, in 1995 the level of service on BPK (i.e., ability to evacuate residents during a hurricane) was found to be inadequate (Lopez et al. 2003*a*). The 2 objectives of the Key Deer-Motorist Conflict Study were to (1) decrease deer-vehicle collisions, and (2) improve US 1 traffic flow. Final study recommendations included (1) construction of barriers (fences and deer guards) with 2 wildlife crossings (underpasses) along an undeveloped segment of US 1 on BPK, and (2) an extra northbound lane through the developed segment of US 1 (hereafter US 1 corridor project; Calvo 1996; Fig. 2.2). A portion of US 1, the developed "business" segment which includes the extra traffic lane, was not fenced due to potential economic losses (i.e., restricted business access in an area with a tourist-based economy; Calvo 1996, Lopez et al. 2003*a*).

Fencing in combination with wildlife crossings has proven to successfully reduce deer-vehicle collisions in many parts of the country (Bellis and Graves 1971, Reed et al. 1975, Falk et al. 1978, Ford 1980). For exclusion fencing to be effective, access management (e.g., fence ends, side roads) is a critical factor (Peterson et al. 2003). US 1 access management was important because of the relatively short length of fenced road (2.6 km) and the number of access points (n = 4) along this segment which made the likelihood of deer going around the ends of the fence high (Reed et al. 1979, Ward et al. 1980, Foster and Humphrey 1995).

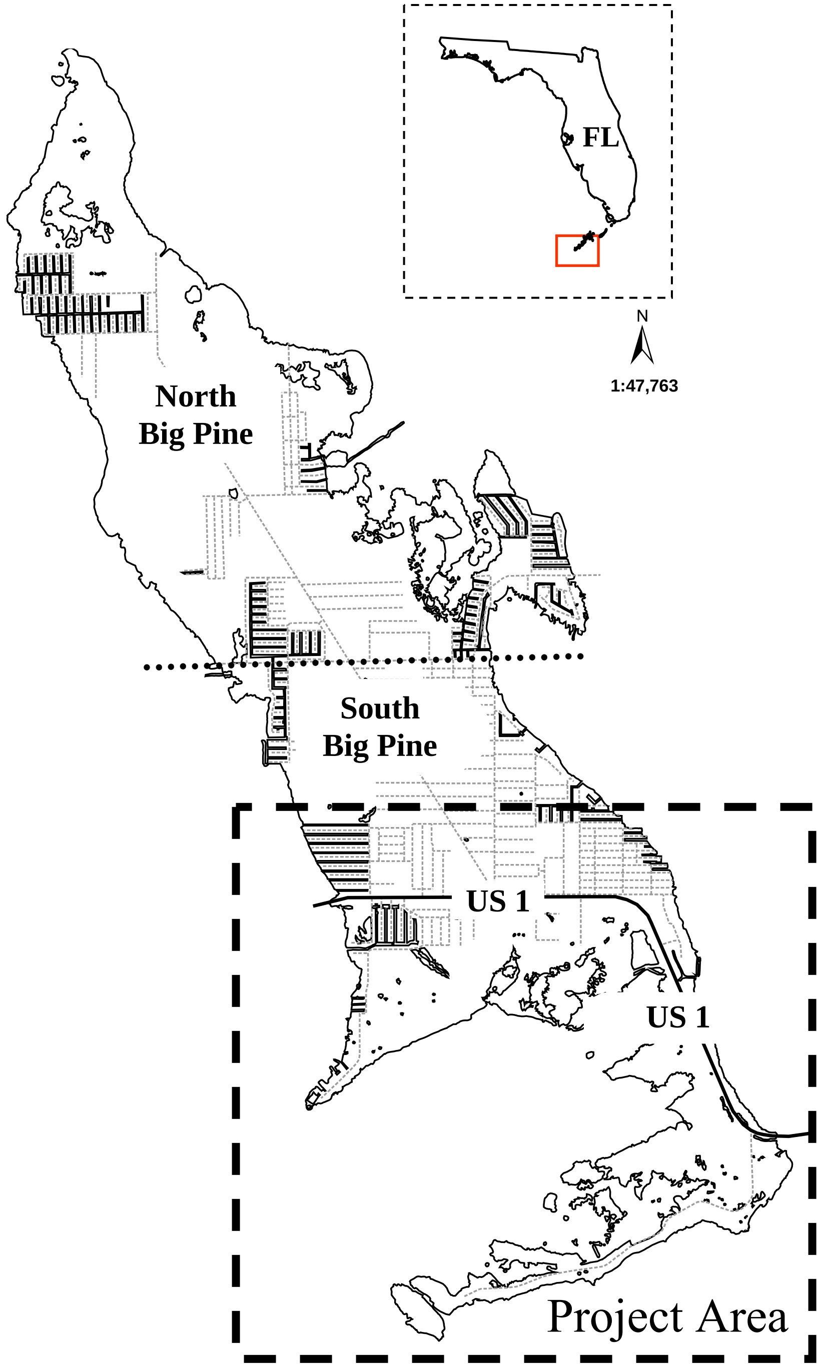

Figure 2.1. Roadways (US 1 [solid line], other roads [dashed gray lines]), and project area on Big Pine Key (north and south, separated by dotted line), Monroe County, Florida, 2004.

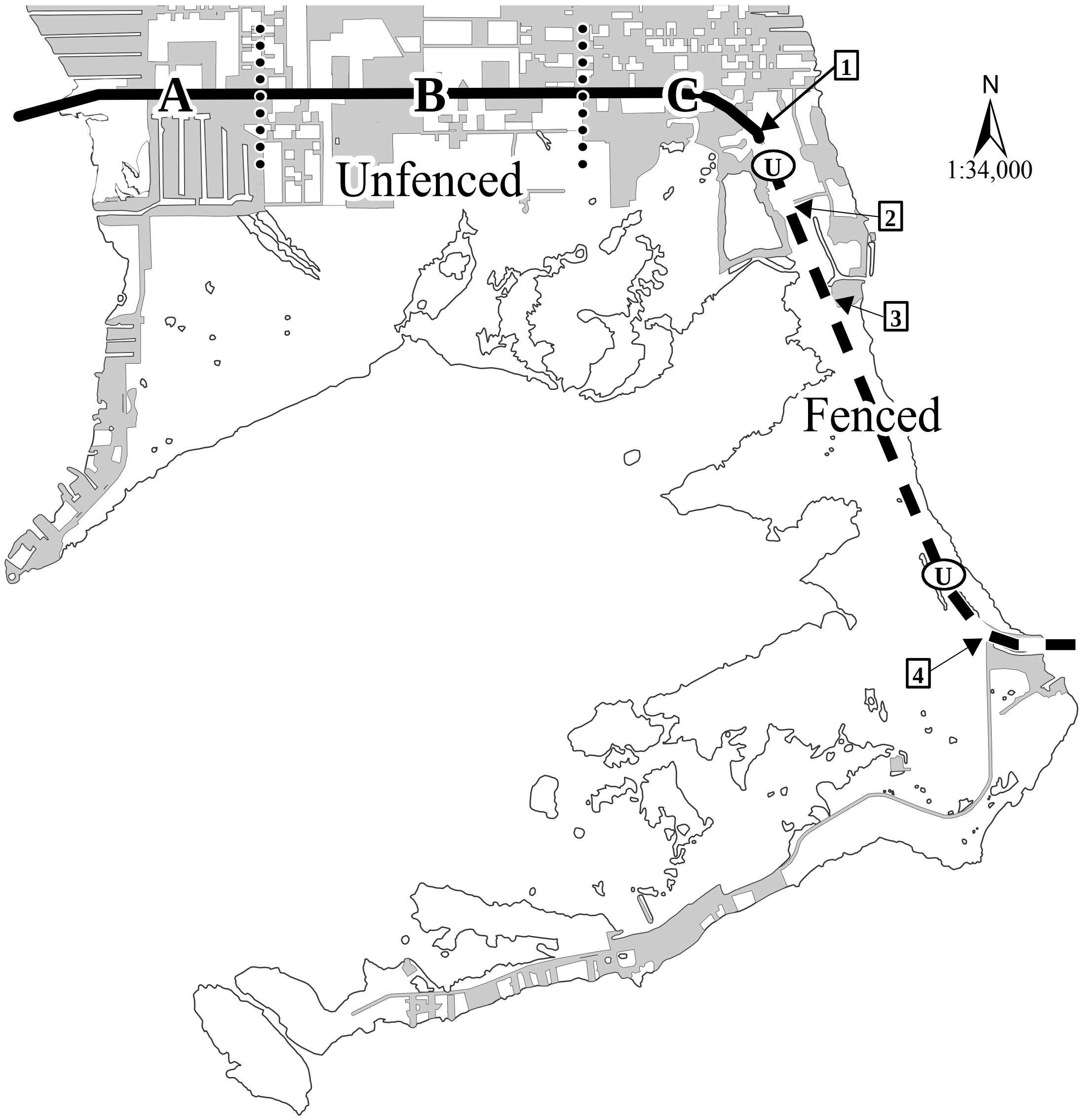

Figure 2.2. Project area for US 1 (5.6 km) corridor project on Big Pine Key, Florida, 2002. US 1 is divided into unfenced (3.1 km, solid line [A + B + C]) and fenced (2.6 km, dashed line) segments. The unfenced road section consists of a west (0.8-km [A]), extra lane (1.4 km [B]), and east (0.8 km [C]) segment. The fenced section includes 2 underpasses (denoted by U) and 4 experimental deer guards (indicated by arrows and numbered). Gray areas denote developed areas.

Traditionally, modified cattle guards or “deer guards” that allow unrestricted vehicle access were used to exclude deer at fence ends (Reed et al. 1974, Reed et al. 1979, Woods 1990, Sebesta 2000). However, traditional deer guards used evenly-spaced rectangular beams (Reed et al. 1974) or tubing (Belant et al. 1998), which posed a hazard to pedestrians and cyclists in the US 1 corridor project, and were unproven in supporting heavy vehicular loads (Peterson et al. 2003). Peterson et al. (2003) recommended using a standard bridge grating material with 10.1 x 12.7-cm rectangular openings with a diagonal cross member, which was found to be 98% efficient at excluding Key deer access during 7-day baited pen trials on BPK. In addition to the deer guards, 2 concrete underpasses (14 x 8 x 3 m) were constructed along the fenced segment to reduce the motivation for deer to enter the fenced segment (Calvo 1996, Ward 1982, Clevenger et al. 2001).

In 2002, construction of the 2.6-km fenced segment, 2 underpasses, 4 experimental deer guards (Peterson et al. 2003), and the extra 1.4-km traffic lane were completed. Based on the project design, USFWS biologists estimated (1) a 66% reduction in deer-vehicle collisions along the fenced segment due to deer entering the fenced segment and deer-vehicle collisions at fence ends, and (2) a 50% increase in deer-vehicle collisions in the unfenced segment as a result of additional traffic associated with the extra lane (Key Deer Habitat Conservation Plan 2005, under review). However, with no similar Key deer road improvement projects in existence, there was no information on which to base these estimates. With the US 1 corridor project completed, the objective of my study was to evaluate the effectiveness of fencing, underpasses, and experimental deer guards in reducing Key deer mortality by (1) comparing pre-fence and post-fence survival of radio-collared deer, (2) comparing pre-fence and post-fence deer-vehicle collisions on US 1, and (3) determining the ability of deer to access the fenced segment.

METHODS

My study was conducted on the southern half of BPK, Florida. US 1 is a 2-lane highway that links the Keys to the mainland with an estimated annual average daily traffic volume of approximately 18,000 vehicles/day (Florida Department of Transportation, Monroe County 2004). US 1 (5.6 km) bisects BPK on the southern half of the island (Fig. 2.1). Maximum speed limits are 72 km/hr during the day and 56 km/hr at night. Vegetation near sea level and in tidal areas on BPK is comprised of black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*) forests. With increasing elevation, maritime zones transition into hardwood (e.g., gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipula*] and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) upland forests with vegetation intolerant of salt water (Dickson 1955, Folk 1991, Lopez et al. 2004*b*).

Radio-Collared Deer Survival

Trapping.—Florida Key deer were radio-collared along the US 1 project area as part of 2 separate research projects conducted January 1998–December 2000 (Lopez 2001; hereafter "pre-fence" period) and February 2003–January 2004 (this study, hereafter "post-fence" period) on BPK. I captured Key deer with portable drive nets

(Silvy et al. 1975), drop nets (Lopez et al. 1998), and hand capture (Silvy 1975). I used physical restraint to hold animals (no drugs were used) with an average holding time of 10–15 minutes. Captured Key deer were marked in various ways depending on sex and age (Lopez 2001). I used a battery-powered, mortality-sensitive radio transmitter (100–110 g for plastic neck collars, 10–20 g for antler transmitters and elastic collars, Advanced Telemetry Systems, Isanti, Minnesota, USA) attached to plastic neck collars (8-cm wide, primarily females of all age classes), leather and nylon antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, primarily male fawns/yearlings). Each captured animal received an ear tattoo as a permanent marker (Silvy 1975). For each radio-tagged deer, I recorded sex, age (fawn, yearling, adult; Severinghaus 1949), capture location, body mass (kg), and transmitter frequency (MHz) prior to release.

Radiotelemetry.—I monitored radio-collared deer using a 3-element Yagi antenna and automatic scanning receiver (Samuel and Fuller 1996) for mortalities 6–7 times/week at random intervals. I randomly selected a 4-hr segment for each 24-hr period during which all deer were relocated via homing (Lopez 2001). If a mortality signal was detected, I immediately located and necropsied the animal to determine cause of death (Nettles 1981). I censored animals if radios failed or disappeared (Pollock et al. 1989).

Deer-Vehicle Collisions

Data collection.—Since 1966, USFWS biologists have recorded Key deer mortality on all roads on BPK via direct sightings, citizen and law enforcement reports, and observation of turkey vultures (*Cathartes aura*, Lopez et al. 2003*b*). Age, sex, and body mass were recorded for each dead animal, and all road-related deer mortality locations were entered into a Geographical Information System (GIS) using ArcView (Version 3.2) and Microsoft Access (Version 2000).

Deer Guard Crossing Events

Data collection.—Since the completion of the US 1 corridor project (Feb 2003–present), USFWS biologists have recorded the number, age, sex, and point of entry of all known deer inside the fenced segment based on direct sightings and local law enforcement reports. Removal of deer from the fenced segment was conducted when necessary using maintenance side gates (n = 16) installed during initial construction.

Data Analysis

Radio-collared deer survival.—I used the Kaplan-Meier estimator modified for staggered entry which allows for censored individuals (Pollock et al. 1989) to calculate sex-based survival (S) on a 365-day period beginning February 2004. Survival was calculated using the program Ecological Methodology (Krebs 1999). Lopez et al. (2003*b*) reported yearling and adult survival by sex was similar, therefore, age-classes (yearlings, adults) were pooled in my study. Data from fawn age-classes were excluded from my analysis due to small sample sizes. I tested for differences between periods by sex using the generalized Chi-square testing procedure described by Sauer and Williams (1989) with the program CONTRAST (Hines and Sauer 1989). Survival estimates reported by sex for south BPK Key deer (pre-fence period; Lopez et al. 2003*b*) were used for comparison.

Deer-vehicle collisions.—Using the USFWS road mortality data, I compared annual pre-fence (1996–2000) US 1 deer-vehicle collisions to post-fence (2003–2004) annual US 1 deer-vehicle collisions by sex, age, and area (US 1 road segments, Fig. 2.2). Key deer mortality data from 2001–2002 were excluded to avoid biases during the construction phase of the project.

RESULTS

Radio-Collared Deer Survival

I captured and radio-collared 46 deer (29 females, 17 males). Five deer died (4 female and 1 male), 15 survived, and 26 deer were censored due to collar/battery failure over the course of the study. Mortality agents of the 5 radio-collared deer that died included US 1 deer-vehicle collisions (n = 3), a dog attack (n = 1), and an unknown agent (n = 1). Key deer annual post-fence survival (female = 0.802 ± 0.089 SE, male = 0.667 ± 0.272 SE) was similar to pre-fence estimates (female = 0.710 ± 0.082 SE, male = 0.412 ± 0.099 SE, Fig. 2.3).

Deer-Vehicle Collisions

Deer-vehicle collisions decreased approximately 83–92% (from 12–24 [in 1996–2000] to 1 [in 2003]) following the completion of the US 1 corridor project for the fenced section, however; there was a 13–125% increase (from 4–8 [in 1996–2000] to 9 [in 2003]) in deer-vehicle collisions in the east segment (i.e., the segment associated with “fence end” deer-vehicle collisions; Figs. 2.2 & 2.4). Combined, fencing project (east and fenced segments) deer-vehicle collisions decreased 45–66% (from 20–32 [in 1996–2000] to 11 [in 2003]). Deer-vehicle collisions along the extra lane segment increased 21–113% (from 8–14 [1996–2000] to 17 [in 2003]) from pre-fence to post-fence periods. In general, deer-vehicle collisions increased in all unfenced segments (east, extra lane, west). However, total US 1 (all segments) deer-vehicle collisions did not change during the post-fence period. No change was observed in the distribution of sex and ages of deer involved in deer-vehicle collisions between periods (pre-fence, post-fence).

Deer Guard Crossing Events

Eight deer entries into the fenced segment were recorded (6 deer-guard crossings, 2 open side-gate entries) following the completion of the project. A majority of deer guard crossings occurred at night (*n* = 4; 2 adult males, 2 adult females) rather than during the day (*n* = 2; 2 adult males). The 8 deer incidents resulted in 2 Key deer mortalities within the fenced segment of the project (*n* = 1, vehicle collision; *n* = 1, severe injury during removal attempt, euthanized). Of the 6 surviving deer, 4 deer crossed back over deer guards to exit the fence and 2 deer exited through side gates.

DISCUSSION

Radio-Collared Deer Survival

I found little change in survival between the pre- and post-fence period for radio-collared deer in my study. I attributed this finding to overall US 1 Key deer-vehicle collisions remaining relatively unchanged from pre- to post-fence periods. Observed decreases in deer-vehicle collisions along the fenced section were negated by increases along the unfenced section.

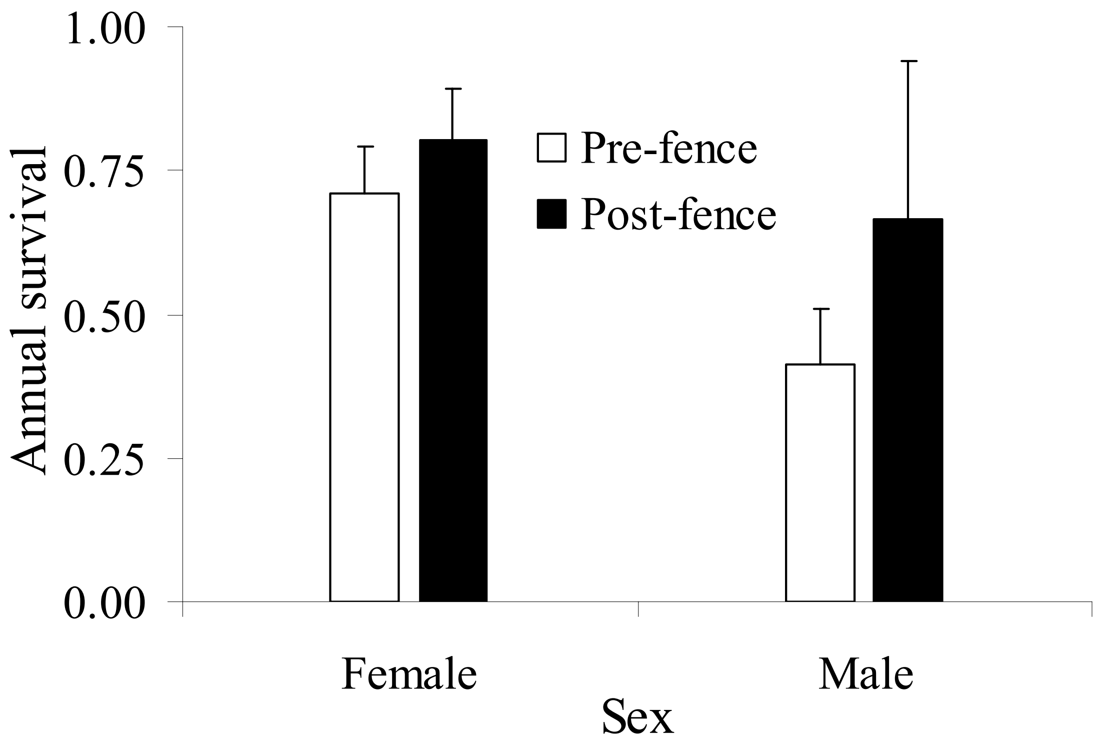

Figure 2.3. Annual Florida Key deer survival (*S*, 1 SE) by sex and study period (pre-fence, 1996–2000; post-fence, 2003) for radio-collared yearlings and adults on south Big Pine Key, Florida.

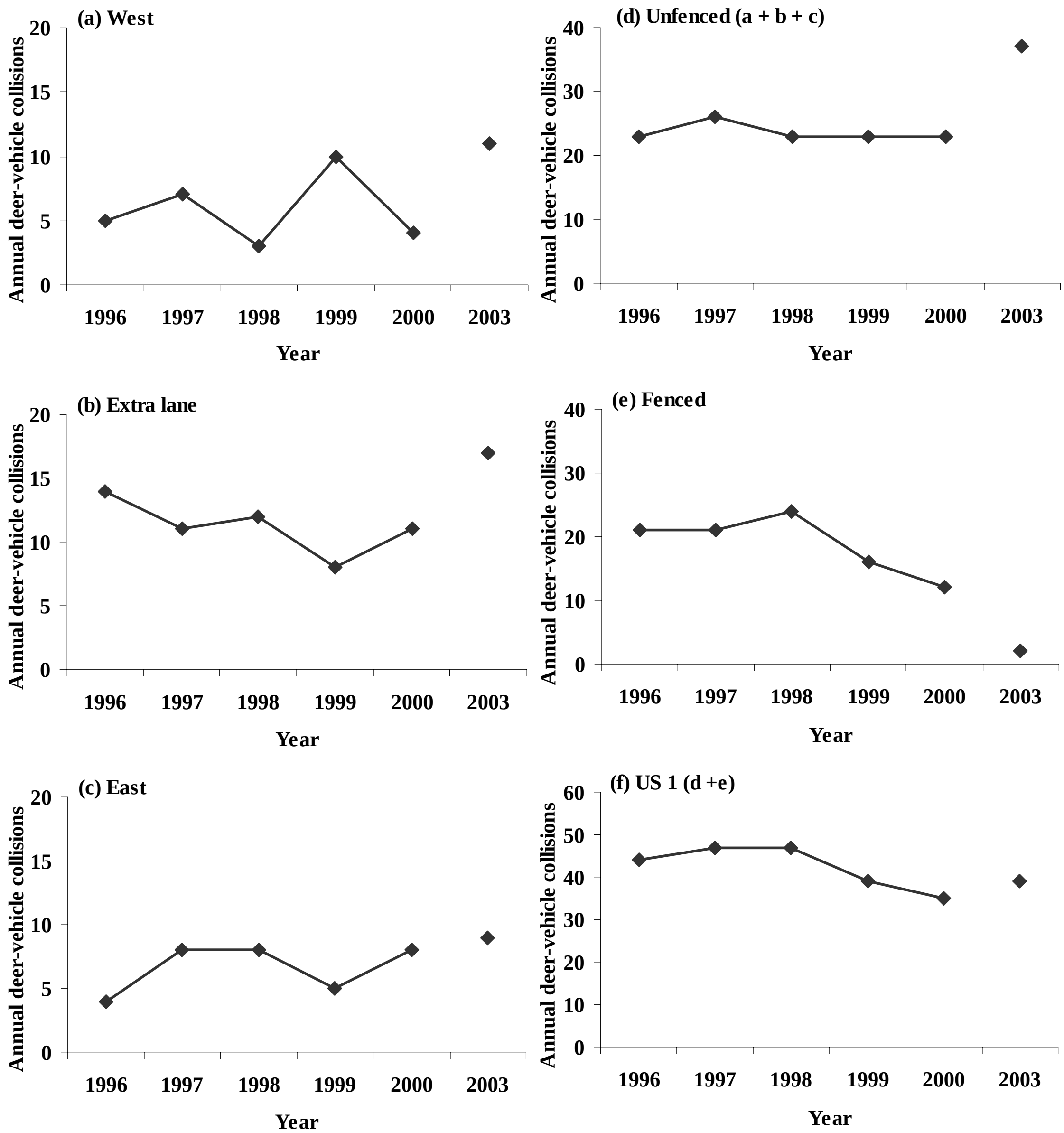

Figure 2.4. Annual Key deer-vehicle collisions by US 1 road segment (west, extra lane, east, fenced segment) and combined segments (unfenced and US 1) for pre-fence (1996–2000) and post-fence (2003) periods on Big Pine Key, Florida.

Additionally, survival estimates included non-US 1 related mortality factors (e.g., dog attacks, disease, drowning) which account for as much as 25–50% of annual losses (Lopez et al. 2003*b*). However, it must be noted that small post-fence sample sizes and a shorter post-fence study period (1 year post-fence compared to 2 years pre-fence) may have contributed to the inconclusive results.

Deer-Vehicle Collisions

I found a decrease (83–92% depending on year) in deer-vehicle collisions along the fenced section following the projects completion which agrees with results found elsewhere (Reed et al. 1982, Ludwig and Bremicker 1983, Woods 1990). As is the case with many deer exclusionary fencing projects, 100% effectiveness (i.e., no deer inside the fence) was not achieved and was believed to be an impractical goal (Woods 1990, Putman 1997, Key Deer Habitat Conservation Plan 2005, under review). With the understanding that some deer will cross into the roadway, strategies for safe removal of incidental deer from the fenced section becomes necessary. This became evident after 1 deer was euthanized after receiving a severe fence-induced wound during its removal.

The post-fence increase in deer-vehicle collisions along the unfenced section is likely the result of several factors. The east segment increase is located at the fencing's end (Fig. 2.2). Previous studies have shown an increase in deer-vehicle collisions associated with fence ends (Ward 1982, Feldhammer et al. 1986, Clevenger et al. 2001), and USFWS biologists expected an increase in deer-vehicle collisions in the east segment as a result (Key Deer Habitat Conservation Plan 2005, under review). Factors associated with the addition of the extra 1.4-km traffic lane in the corresponding segment are believed responsible for the post-fence collision increases in both the extra lane and west segments. I presumed the increase in mortality in the extra lane occurred due to the associated increased traffic flow (higher average speeds, more vehicles/hr), reduced deer visibility, and the additional hazard of deer having to cross 3 lanes of traffic versus 2 (Lopez et al. 2003*a*, Key Deer Habitat Conservation Plan 2005, under review). The deer-vehicle collisions increase along the west segment was not foreseen. It was possible that some deer chose to avoid the extra-lane segment and crossed US 1 in the west segment, resulting in additional deer-vehicle collisions in that segment. Although, the extra lane was believed responsible for both direct and indirect (i.e., shift from extra lane to west segment) deer-vehicle collision increases in the unfenced segments, with time; I believe US 1 unfenced segment Key deer-vehicle collisions will decline as deer adjust to the altered traffic over a longer acclimation period following the project's completion (Reed et al. 1975, Clevenger 1998, Hardy et al. 2003).

Deer Guard Crossing Events

Deer crossed the guards 6 times to enter the fenced segment which includes 4 experimental deer guards proposed by Peterson et al. (2003). Although pen trials found the deer guards to be 98% effective, I was unable to determine how many crossing attempts occurred during the pre- or post-fence periods. The finding of all deer crossings involving adults supports the theory that larger hoof sizes allow for more successful crossings (Peterson et al. 2003). Factors that may explain some of the deer crossings were a fencing adjustment period and Key deer sociobiology. Previous fencing studies have found that an acclimation period exists with wildlife fencing structures (Reed et al. 1975, Clevenger 1998, Hardy et al. 2003). Additionally, Key deer are known to have strong site and movement pattern fidelity (Lopez 2001). These 2 factors resulted in deer crossings as attempts were made to revert to pre-fence movements and ranges. The number of these “reminiscence” deer crossings should decrease as older deer acclimate to the location of crossings and as younger deer establish ranges with the fencing project in place.

MANAGEMENT IMPLICATIONS

Post-fence data indicate the US 1 fencing project reduced Key deer-vehicle collisions along a portion of US 1. Although overall US 1 deer-vehicle collisions did not change between periods due to deer-vehicle collision increases in the unfenced section, I believe collisions in this section will decrease as deer become habituated to the project and their movements stabilize. With both the Key deer population (Lopez et al. 2004*a*) and traffic levels (Florida Department of Transportation data, Monroe County, 2004) on BPK increasing, it is likely that Key deer-vehicle collisions along other BPK and surrounding island roads will become a concern for USFWS biologists in the future. Unable to fence all roads within the Key deer’s range, different strategies to reduce deer-vehicle collisions in these areas will need to be developed.

Deer guards, in combination with fencing and underpasses, proved effective at reducing deer access into fenced segments of US 1 with no compromise of human safety (i.e., no reported human deer guard accidents). As more deer-vehicle collision issues develop in other suburban-type habitats, restricting deer access without interfering with human activities will become more important. The US 1 corridor project demonstrates one design for addressing these issues.

CHAPTER III

FLORIDA KEY DEER UNDERPASS USE AND MOVEMENTS ALONG THE US 1 CORRIDOR

SYNOPSIS

In order to address endangered Florida Key deer (*Odocoileus virginianus clavium*) vehicle collisions along a 5.6-km segment of United States Highway 1 (US 1), the Florida Department of Transportation (FDOT) constructed a 2.6-km long system of fencing, deer guards, and 2 underpasses to exclude deer from the roadway and maintain deer movements on Big Pine Key (BPK), Florida in 2002. To evaluate the potential impacts of highway modifications (i.e., fencing, underpasses) to Key deer movements, I compared (1) the annual ranges and movements of radio-collared Key deer pre- (January 1998–December 2000) and post underpass construction (February 2003–January 2004), and (2) underpass use within the corridor project following construction. Female and male annual ranges and core areas did not change ($P > 0.05$) between pre- and post-project. Deer movements within the US 1 corridor were comparable pre- (6 of 23 radio-collared deer crossed the corridor) and post-project (4 of 16). Infrared-triggered camera data indicate underpass movements increased over time, suggesting an acclimation period is necessary for highway underpasses to be successful. Collectively, post-project data indicates highway improvements to the US 1 corridor have not restricted Key deer movements while minimizing Key deer mortality at a large-scale; however, study results suggest changes in deer movement patterns at a smaller (within-corridor) scale. Wildlife

managers and transportation planners should make efforts to enhance corridor movements at both large and small scales.

INTRODUCTION

The extensive 6.3 million-km road network of the United States has substantial ecological impacts on many wildlife species (Andrews 1990, Spellerberg 1998, Forman 2000, Forman et al. 2003). Two impacts of interest along roadways include mortality from vehicle collisions and reduced animal movements (Bennett 1991, Forman and Alexander 1998, Ruediger 1998, Cain et al. 2003). One solution that addresses road mortality has been to restrict wildlife access to roads (e.g., fencing, concrete barriers), which has been shown to effectively benefit local populations (i.e., fewer animal-vehicle collisions; Reed et al. 1974, Ludwig and Bremicker 1983, Clevenger et al. 2001). However, restricting access can lead to decreased animal movements that may result in relatively greater impacts such as genetic depression or maintaining population viability (Wilcox and Murphy 1985, Saunders and Hobbs 1991, Jackson 2000, Forman et al. 2003). Maintaining animal movements is especially important in the recovery and mitigation of endangered species (e.g., Florida panther [*Felis concolor coryl*], Foster and Humphrey 1995; Florida Key deer [*Odocoileus virginianus clavium*], Klimstra et al. 1974, Folk 1991). To eliminate potential movement issues, wildlife crossings (e.g., overpasses, underpasses) have been incorporated in some transportation projects (Foster and Humphrey 1995, Romin and Bissonette 1996, Forman et al. 2003). Previous studies have demonstrated the use of crossing structures (e.g., underpasses, overpasses) by several wildlife species to transverse restricted roadways (Reed et al. 1975, Foster and

Humphrey 1995, Clevenger 1998, Wieren and Worm 2001, Ng et al. 2004); however, few studies have assessed if these crossing structures maintain animal movements (Simberloff et al. 1992, Romin and Bissonette 1996, Beier and Noss 1998).

Florida Key deer are the smallest subspecies of white-tailed deer in the United States (Hardin et al. 1984), occupying 20–25 islands in the Lower Florida Keys (Lopez 2001). Approximately 65% of the overall population is found on BPK (Lopez et al. 2004*a*), which serves as a source population for surrounding islands (Klimstra et al. 1974, Hanski and Gilpin 1997). Since the 1960s, deer-vehicle collisions have been the single largest Key deer mortality factor accounting for >50% of annual losses (Silvy 1975, Lopez et al. 2003*b*). Sixty-nine Key deer-vehicle collisions were recorded on BPK in 2000 (United States Fish and Wildlife Service [USFWS], unpublished data). Because of this, United States Fish and Wildlife Service (USFWS) and Florida Department of Transportation (FDOT) biologists have attempted to address deer-vehicle collisions on United States Highway 1 (US 1) which bisects BPK (Fig. 3.1). In 1994, the Key Deer-Motorist Conflict Study was initiated by FDOT to evaluate alternatives for reducing deer-vehicle collisions along the US 1 corridor (Calvo 1996). During the planning process, deer movements were of concern because the proposed US 1 corridor project area was a narrow (<150 m) natural corridor and the sole land connection between north and south BPK (south BPK also joins Newfound Harbor Keys, Fig. 3.1).

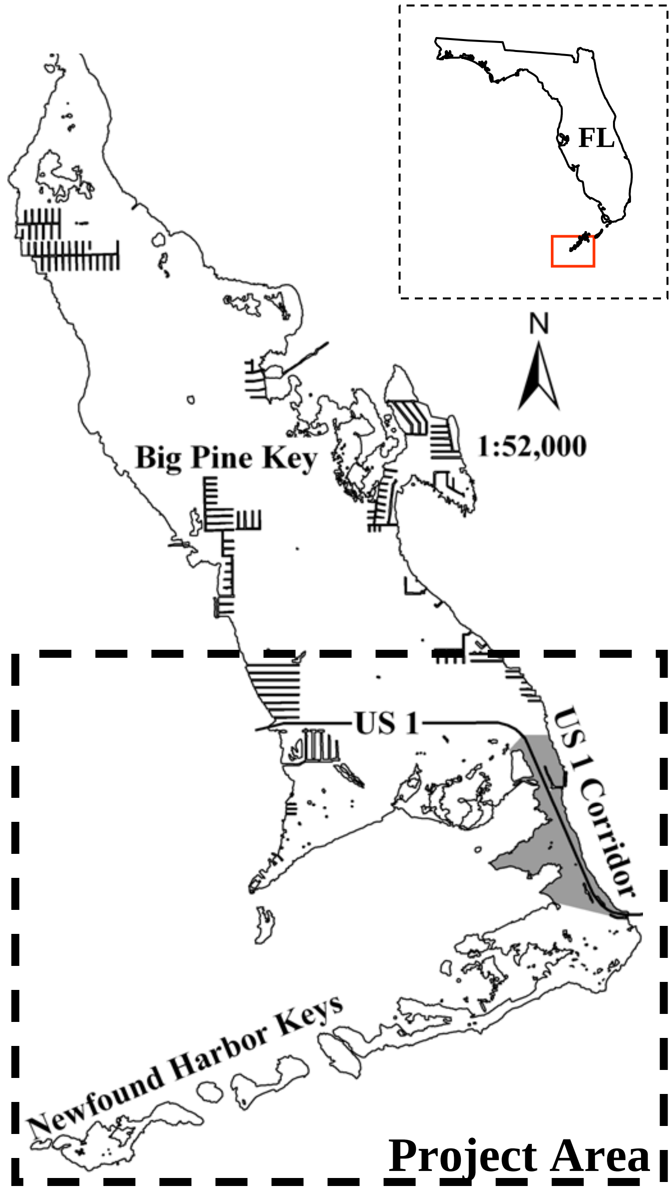

Figure 3.1. The project area (dashed line) including US 1 (black line), US 1 corridor (gray shaded area), south Big Pine Key (BPK, south of US 1 corridor), north BPK (north of US 1 corridor), and Newfound Harbor Keys, Monroe County, Florida, 2004.

A recent study of Key deer movements reported that deer on north BPK served as a "source" population for deer populations in south BPK (Harveson et al. 2004), emphasizing the importance of understanding deer movements within the proposed project area. Final study recommendations included construction of barriers (fences) with 4 deer guards and 2 wildlife crossings (underpasses) along an undeveloped segment of US 1 on BPK (hereafter US 1 corridor project; Calvo 1996, Lopez et al. 2003*a*). In 2002, construction of the 2.6-km fenced segment with 2 box underpasses (14 m x 8 m x 3 m) and 4 experimental deer guards (Peterson et al. 2003) was completed.

My study objective was to assess the potential impacts of US 1 corridor highway improvements on BPK to Key deer movements. Specifically, my study objectives were to (1) compare southern BPK radio-collared Key deer annual ranges (95% and 50% probability areas) pre- and post-project, (2) compare radio-collared deer corridor movements pre- and post-project, and (3) assess Key deer underpass and corridor use post-project using infrared-triggered cameras.

METHODS

US 1 is a 2-lane highway that links the Keys to the mainland with an estimated annual average daily traffic volume of approximately 18,000 vehicles/day (FDOT data, Monroe County, 2004). US 1 bisects the southern half of BPK with maximum speed limits of 72 km/hr during the day and 56 km/hr at night (Fig. 3.1). Vegetation near sea level and in tidal areas on BPK is comprised of black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*) forests. With increasing elevation, maritime zones transition into hardwood (e.g., gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipula*] and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) upland forests with vegetation intolerant of salt water (Dickson 1955, Folk 1991, Lopez et al. 2004*b*).

Trapping and Radiotelemetry

Florida Key deer were radio-marked as part of 2 separate research projects conducted January 1998–December 2000 (Lopez 2001, hereafter “pre-project”) and February 2003–January 2004 (this study, hereafter “post-project”) on BPK. I captured Key deer with portable drive nets (Silvy et al. 1975), drop nets (Lopez et al. 1998), and hand capture (Silvy 1975). I used physical restraint to hold animals (no drugs were used) with an average holding time of 10–15 min. Captured Key deer were marked in various ways depending on sex and age (Lopez 2001). I used a battery-powered, mortality-sensitive radiotransmitter (100–110 g for plastic neck collars, 10–20 g for antler transmitters and elastic collars, Advanced Telemetry Systems, Isanti, Minnesota, USA) attached to plastic neck collars (8-cm wide, females of all age classes), leather and nylon antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, male fawns/yearlings). Each captured animal received an ear tattoo as a permanent marker (Silvy 1975). For each radio collared deer, I recorded sex, age (fawn, yearling, adult; Severinghaus 1949), capture location, and body mass. I relocated radio-marked deer via homing (White and Garrott 1990, Lopez 2001) 6–7 times/week at random intervals (24-hr period was divided into 6 equal 4-hr segments; 1

[4-hr] segment was randomly selected, and during that time all deer were located [Silvy 1975]). Telemetry locations were entered into a GIS using ArcView (Version 3.2).

Camera Transects

TrailMaster 1500 Active Infrared Trail Monitors (TrailMaster, Goodson and Associates, Inc., Lenexa, Kansas, USA) consisting of a transmitter, receiver, and a 35-m camera (Jacobson et al. 1997) were placed in the center of each underpass (north underpass, south underpass) and perpendicular to the US 1 roadway across the full width of the corridor (hereafter camera transect; west transect = 7 cameras; east transect = 1 camera) to monitor deer underpass and corridor movement, respectively (Fig. 3.2). The number of west and east transect cameras differed due to transect lengths (west transect = 90 m, east transect = 14 m). Camera stations collected data for 1 yr (February 2003–January 2004) following project completion. Cameras were set to take pictures throughout the day (0001–2400 hrs) with a camera delay of 2 minutes (Jacobson et al. 1997). The number, sex, age, and location of deer were recorded and entered into an Access database.

Data Analysis

Ranges and core areas.—I compared Key deer annual ranges pre- and post-project from telemetry data (Objective 1). In an attempt to evaluate effects of highway improvements, my analysis of movements and ranges were restricted to radio-collared deer with >90% of their locations within the project area.

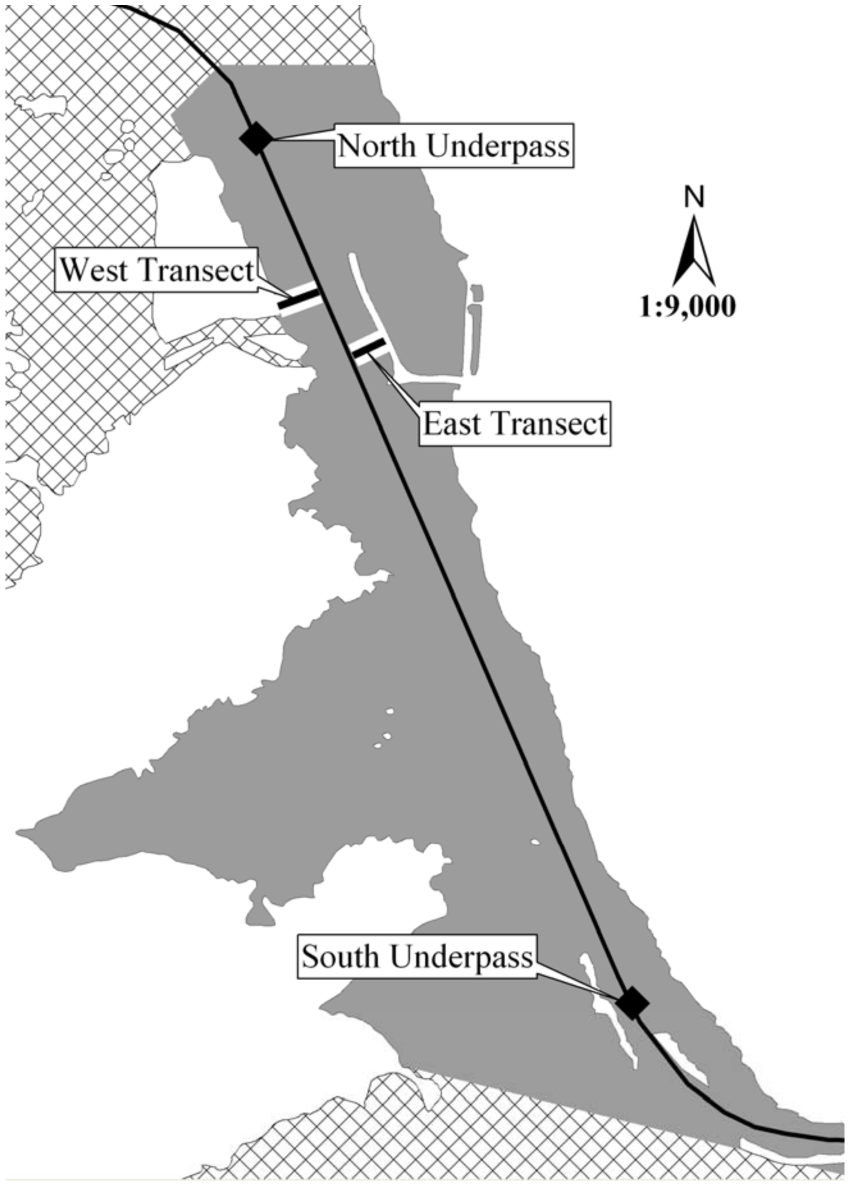

Figure 3.2. The US 1 corridor (shaded area, crosshatched area=other land mass) and denoted infrared-triggered camera transects used to monitor Key deer movements on Big Pine Key, Florida, 2003. Note that camera transects terminate into water bodies (i.e., canals, bay).

I calculated Key deer annual ranges (95% probability area) and core areas (50% probability area) using a fixed-kernel home-range estimator (Worton 1989, Seaman et al. 1998, Seaman et al. 1999) with the animal movement extension in ArcView (Version 2.2; Hooge and Eichenlaub 1999). Calculation of the smoothing parameter (kernel width) as described by Silverman (1986) was used in generating kernel range estimates. Annual ranges (ha) and core areas (ha) of yearling and adult deer were calculated by sex for each period (pre-project, post-project). I used the nonparametric Mann-Whitney U-test to compare differences in Key deer ranges and core areas by period and sex at $\alpha = 0.05$.

Corridor use and movement patterns.—I compared the frequency of radio-collared Key deer that crossed the corridor pre- and post-project (Objective 2). To compare the number of radio-collared deer that crossed the corridor, I assigned individual deer telemetry locations to a given category: (1) within US 1 corridor area, (2) north of US 1 corridor area, and (3) south of US 1 corridor area. Key deer with locations in all 3 areas were classified as haven crossed the corridor. Key deer with locations within the corridor and on only 1 side of the corridor (north or south, but <u>not</u> both) were classified as non-crossers. I also evaluated radio-collared Key deer movements inside the US 1 corridor area with respect to their position to US 1 along the corridor (i.e., west or east side of US 1; Fig. 3.1). The number of collared deer that used both sides of US 1 (west and east) versus only 1 side (either west or east) was compared between the pre- and post-project periods using a Chi-square test to evaluate movement patterns within the corridor itself (SPSS 2001).

Underpass use.—I compared Key deer underpass and corridor use post-project using infrared-triggered camera data (Objective 3). I compared average monthly camera exposures between underpasses and camera transects by semi-annual period (1–6 months and 7–12 months following the completion of the US 1 corridor project) using Tukey's HSD procedure (*t*-test adjusted for multiple comparisons; SPSS 2001). I also compared underpass and corridor use using performance ratios as described by Clevenger and Waltho (2000). A performance ratio (*PR*) is a relative measure of observed crossing frequencies compared to expected crossing frequencies (*PR* = observed/expected). Monthly *PRs* were calculated by dividing the observed crossing frequencies (i.e., observed camera exposures) by expected crossing frequencies (i.e., expected camera exposures) by sex, location (underpass [north and south], camera transect [east and west]), and period (1–6 month, 7–12 month). Expected crossing frequencies were determined by taking the total number of monthly camera exposures divided by the number of possible outcomes. For example, if 100 camera exposures were taken in a given month for 2 underpasses, the expected value would be 50 exposures (100 exposures/2 underpasses) assuming animal movements were evenly distributed within the project area (Clevenger and Waltho 2000). Thus, if deer crossing frequencies were evenly distributed, then observed would equal expected (i.e., $PR = 1$). A $PR > 1$ suggests underpass/corridor use is greater than expected while $PR < 1$ suggests avoidance (Clevenger and Waltho 2000). I compared average monthly *PR* between Key deer underpasses and camera transects (i.e., measure of corridor use) using Tukey's HSD procedure to identify differences (SPSS 2001).

RESULTS

Ranges and Core Areas

I captured and radio-collared 76 Key deer during both studies (pre-project = 16 females, 28 males; post-project = 24 females, 8 males). No deer died during capture or from capture-related mortality. Deer (n = 62) with ≥ 25 locations (pre-project = 16 females, 19 males; post-project = 23 females, 4 males) were used for annual range and core area analysis. Pre-project female (45 ha ± 48 SD) and male annual ranges (148 ha ± 176 SD) were similar (P = 0.38 for females, P = 0.57 for males) to post-project ranges (female 73 ha ± 94 SD, male 84 ha ± 80 SD). Furthermore, pre-project female (6 ha ± 8 SD) and male annual core areas (22 ha ± 31 SD) were similar (P = 0.29 for females, P = 0.69 for males) to post-project core ranges (female 12 ha ± 18 SD, male 13 ha ± 12 SD).

Corridor Use and Movement Patterns

Pre- and post-project telemetry data indicate a comparable number of radio-collared deer entered the US 1 corridor (pre-project = about 55% [24/44], post-project = about 53% [17/32]). Of the deer entering the project area (n = 41), the number that crossed the entire corridor at least once was comparable pre- (approximately 26%, 6/23) and post-project (25%, 4/16). The distribution of radio locations within the corridor (use of habitat on both sides of US 1 by individual deer, Fig. 3.1), however, was found to be different (P < 0.01) pre- and post-project. All (9/9) of the pre-project deer had locations on both sides of US 1 (west and east) while only 45% (5/11) of post-project deer had locations on both sides of US 1.

Underpass Use

During the first 6 months, monthly camera transect (west + east) exposures (144 ± 51 SD) were greater ($P < 0.01$) than combined underpass exposures (north + south; 43 ± 22 SD; Fig. 3.3). Monthly camera exposures for months 7–12 after project completion, however, were similar ($P = 0.92$) between the corridor camera transects (108 ± 16 SD) and underpass cameras (121 ± 33 SD, Fig. 3.3).

In comparing corridor and underpass *PRs* by sex, the 1–6 month post-project *PRs* were different for females ($P < 0.01$) and males ($P < 0.01$) with 1.5–1.7 times more corridor use and 0.29–0.50 times less underpass use than expected (Fig. 3.4). Corridor and underpass *PRs* 7–12 months post-project, however, were similar for females ($P = 0.91$) and males ($P > 0.99$, Fig. 3.4). In combining all deer (male + female) at the individual camera transect and underpass level, the west transect *PR* was greater ($P < 0.01$) than both the east camera transect and both underpass *PRs* during months 1–6 (Fig. 3.5). The east transect, north underpass, and south underpass *PRs* were similar ($P > 0.05$) during this period. Following a 6 month acclimation period, all camera transect/underpass *PRs* were similar ($P > 0.05$, Fig. 3.5) during months 7–12. Over time (1–6-month to 7–12-month period), all camera transect/underpass *PRs* shifted closer to 1 (i.e., observed frequencies became closer to expected frequencies) except for the east camera transect (Fig. 3.5).

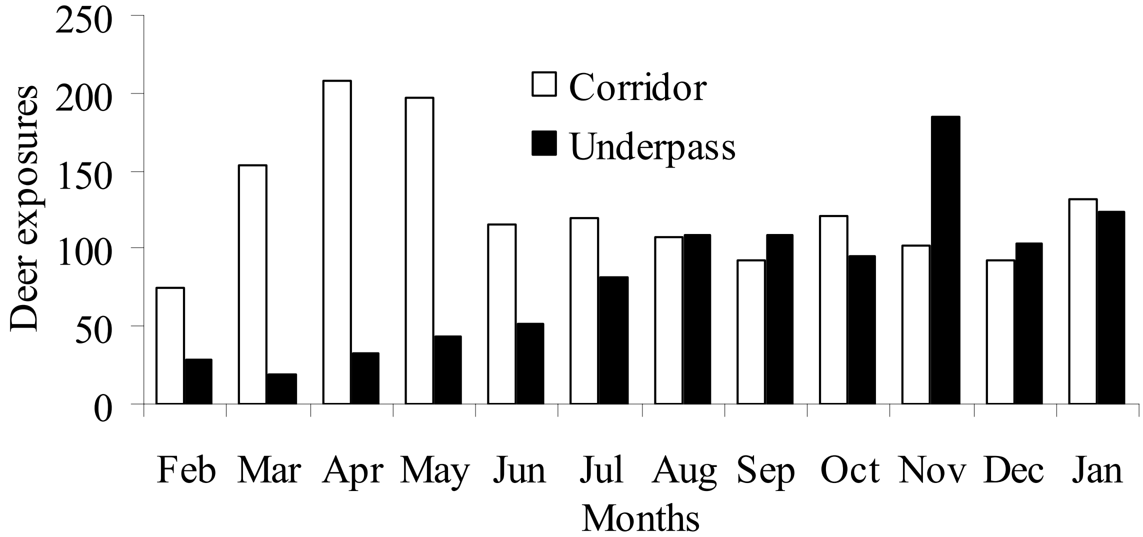

Figure 3.3. Monthly Florida Key deer camera exposures for deer movements along the corridor (west + east camera transects) and underpass (north + south underpasses) following the completion of the US 1 corridor project, Big Pine Key, Florida, 2003.

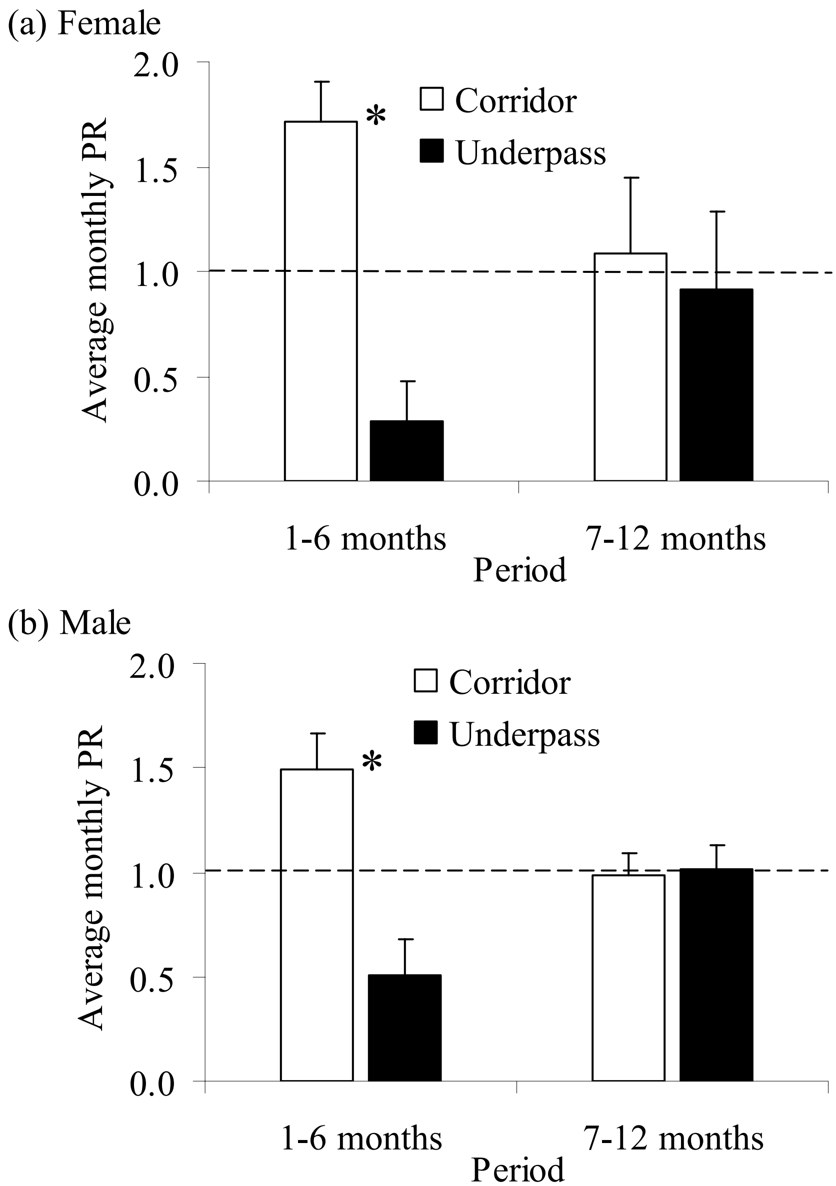

Figure 3.4. Average monthly female (a) and male (b) Key deer performance ratios (*PR*) (mean, 1 SD) by camera transects (corridor [west + east camera transects], underpass [north + south underpasses]) and period (1–6 months, 7–12 months) on Big Pine Key, Florida, 2003. Asterisks indicate a difference at $\alpha = 0.05$.

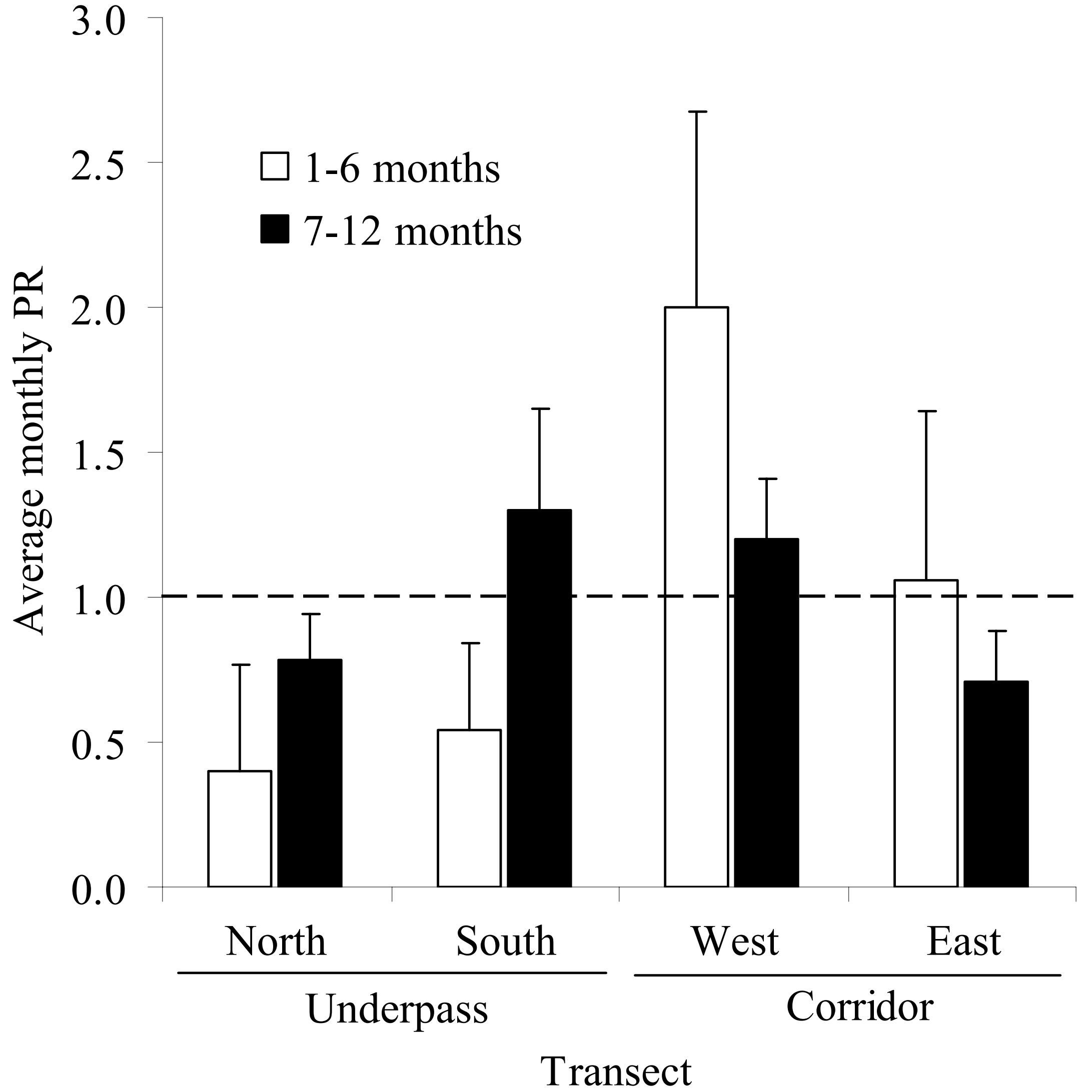

Figure 3.5. Average monthly Key deer performance ratios (*PR*) (mean, 1 SD) by camera transects (underpasses, corridors) and period (1–6 months, 7–12 months) on Big Pine Key, Florida, 2003.

DISCUSSION

Ranges and Core Areas

I found no difference in female or male annual ranges and core areas between the pre- and post-project periods. I attribute this finding to Key deer adapting to the fencing of US 1 (i.e., reshaping of ranges and core areas) and the features of the US 1 corridor project (i.e., underpass locations) to facilitate that adaptation. The lack of differences in ranges pre- and post-project also could be attributed to low sample sizes, which may partially explain the lack of power in my analyses. Because of these factors, determining the impacts of the project on deer ranges and core areas should be interpreted with caution.

Corridor Use and Movement Patterns

I found a comparable number of deer entered the US 1 corridor pre- (about 55%) and post-project (about 53%). Additionally, the number of deer that crossed the corridor (about 25–26%) was comparable between both periods. The post-project corridor movement findings suggest the US 1 corridor project can maintain deer movements at a large scale. I found deer movement patterns within the corridor, however, did change pre- to post-project. All pre-project deer (100%) were recorded using both sides of US 1 compared to about 45% of post-project deer. The distribution of radio-collared deer locations pre- and post-project is important because it suggests altered deer movements at a smaller scale within the corridor. Although the telemetry data found similar proportions of deer entered and traversed the corridor, the routes that deer used to travel through the corridor have changed. I believe changes in corridor use, however, were not detrimental to the viability of the BPK Key deer population, because large scale corridor movements or dispersal between north BPK and south BPK remained intact.

Underpass Use and Movement Patterns

Previous underpass studies (Reed et al. 1975, Ward 1982, Foster and Humphrey 1995, Clevenger and Waltho 2000, Ng et al. 2004) have documented wildlife use of underpasses on transportation projects. An even more challenging question is the number of animals that do *not* use underpasses. The unique features of my study area and the camera transect layout allowed for determining a relative estimate of deer that did *not* use the underpasses (Fig. 3.2). Following the project's completion, I found that initial (months 1–6) corridor camera transect exposures (144 exposures/month) were 3 times that of underpass exposures (42 exposures/month, Fig. 3.3). After a 6 month acclimation period, corridor exposures (108 exposures/month) became similar to underpass exposures (120 exposures/month, Fig. 3.3) in my study. Other studies report similar acclimation periods exist with newly-placed wildlife crossing structures (Reed et al. 1975, Clevenger 1998). This acclimation period was evident for both sexes by *PRs* significantly skewed towards corridor use during months 1–6 which later became similar to underpass exposures by months 7–12 (Fig. 3.4).

At a smaller scale (individual camera transect/underpass level), the west camera transect *PR* was significantly ($P < 0.01$) greater than all other transect/underpass *PR*s (east, north, south) during months 1–6 (Fig. 3.5). Study results suggest that Key deer use of the west-side of US 1 was greater than both the use of underpasses and the east-side of US 1 during months 1–6. By months 7–12, however, all transect/underpass *PR*s were found to be similar. The unique shift of the east transect *PR* (from > 1 to < 1) with time, although not significant, may suggest a reduction in use is occurring at a low level along that side of the corridor (Fig. 3.5). One possible reason for declined east transect movements was the presence of a canal which constricts deer movement to a small strip against the fence relative to the crossing area of the west transect, which is much wider (6x; Fig. 3.2). In comparing Key deer overall underpass use (Fig. 3.5), south underpass use was greater than north underpass use. I attributed this differential underpass use to the lack of alternative crossings in the southern region compared to the north where the fencing project ends < 200 m from the north underpass.

MANAGEMENT IMPLICATIONS

At a large scale, radiotelemetry data indicate the US 1 corridor project has the potential to maintain deer movements between surrounding Key deer habitats. The camera data revealed that an acclimation period existed in the use of box underpasses by Key deer. As Key deer became acclimated to the underpasses (about 6 months), underpass and corridor movements became similar. Wildlife managers and transportation planners should anticipate an acclimation period when assessing animal movements associated with wildlife crossings which likely varies by species (Reed et al. 1975, Waters 1988, Opdam 1997). At a smaller (within-corridor) scale, radiotelemetry and camera data suggest that changes in movement patterns occurred within the corridor as a result of highway improvements. Although full corridor crossings were of greatest concern, the potential for restricted movement within the corridor should not be ignored. Wildlife managers and transportation planners should make efforts to improve and/or maintain movements within corridors by expanding and maintaining vegetative clearings along roadsides and reducing and/or eliminating other obstacles to movement (e.g., fill canals) when possible. Such management practices can ultimately influence overall corridor connectivity within the landscape for species of concern like the Florida Key deer.

CHAPTER IV

TEMPORAL PATTERNS OF KEY DEER-VEHICLE COLLISIONS ON BIG PINE KEY, FLORIDA

SYNOPSIS

Since the 1960's, deer-vehicle collisions (DVCs) have accounted for the majority of annual endangered Florida Key deer (*Odocoileus virginianus clavium*) losses on Big Pine Key (BPK), Florida. Additionally, United States Highway 1 (US 1), which bisects the southern end of BPK, has been responsible for >50% of annual DVCs due in part to high deer densities on BPK and higher traffic volumes (3*x* surrounding BPK roadways). In 2003, the Florida Department of Transportation (FDOT) constructed a system of fencing and deer guards on a segment of US 1 to exclude deer from the roadway which has reduced annual DVCs by 83–95% along this segment. However due to socio-economic factors, fencing the full-length of US 1 and other roads within the Key deer's range were impractical. As DVCs continue to occur on the unfenced segment of US 1, I investigated hourly Key deer movement and US 1 traffic patterns and compared them to annual US 1 DVCs to get a better understanding of the temporal factors related to DVCs. Hourly deer movements showed a positive correlation ($r = 0.505$, $P = 0.012$,) to hourly DVCs for the full circadian period. Hourly US 1 traffic showed a significant ($r = 0.787$, $P = 0.012$)positive relationship with DVCs only during the night period. Evaluation of hourly deer movements and hourly traffic volume on US 1 found hourly DVCs to be the result of a combination between both variables. By learning the hourly factors associated with DVCs, nonstructural countermeasures (speed enforcement, warning lights) can be focused within specific periods to minimize DVCs.

INTRODUCTION

Deer-vehicle collisions (DVCs) have increased in the United States, Canada, and Europe in the last several years (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Putman 1997, Forman et al. 2003). Deer-vehicle collisions result in major human and vehicular consequences (Conover et al. 1995), and can lead to significant impacts to local deer populations (e.g., Florida Key deer [*Odocoileus virginianus clavium*], Lopez et al. 2003*b*). As conditions that promote deer-vehicle interactions increase (e.g., urban sprawl, increased roadways, high deer densities; McShea et al. 1997, DeNicola et al. 2000, Forman et al. 2003), a better understanding of the temporal factors associated with DVCs is imperative in the implementation of preventative strategies that ultimately reduces DVC risk (Haikonen and Summala 2001, Gunson and Clevenger 2003).

Methods to reduce DVCs have been important in the recovery of the endangered Florida Key deer since the 1970s (Silvy 1975, Drummond 1987, Calvo 1996, Lopez et al. 2003*b*). Previous studies report nearly half of the total deer mortality are attributed to DVCs (Lopez et al. 2003*b*), with the majority of these occurring on U.S. Highway 1 (US 1) on Big Pine Key (BPK; Fig. 4.1). High DVCs on US 1 is attributed to increasing deer densities on BPK (Lopez et al. 2004*a*) and increased traffic volumes (3*x*) on surrounding roadways (FDOT 2004).

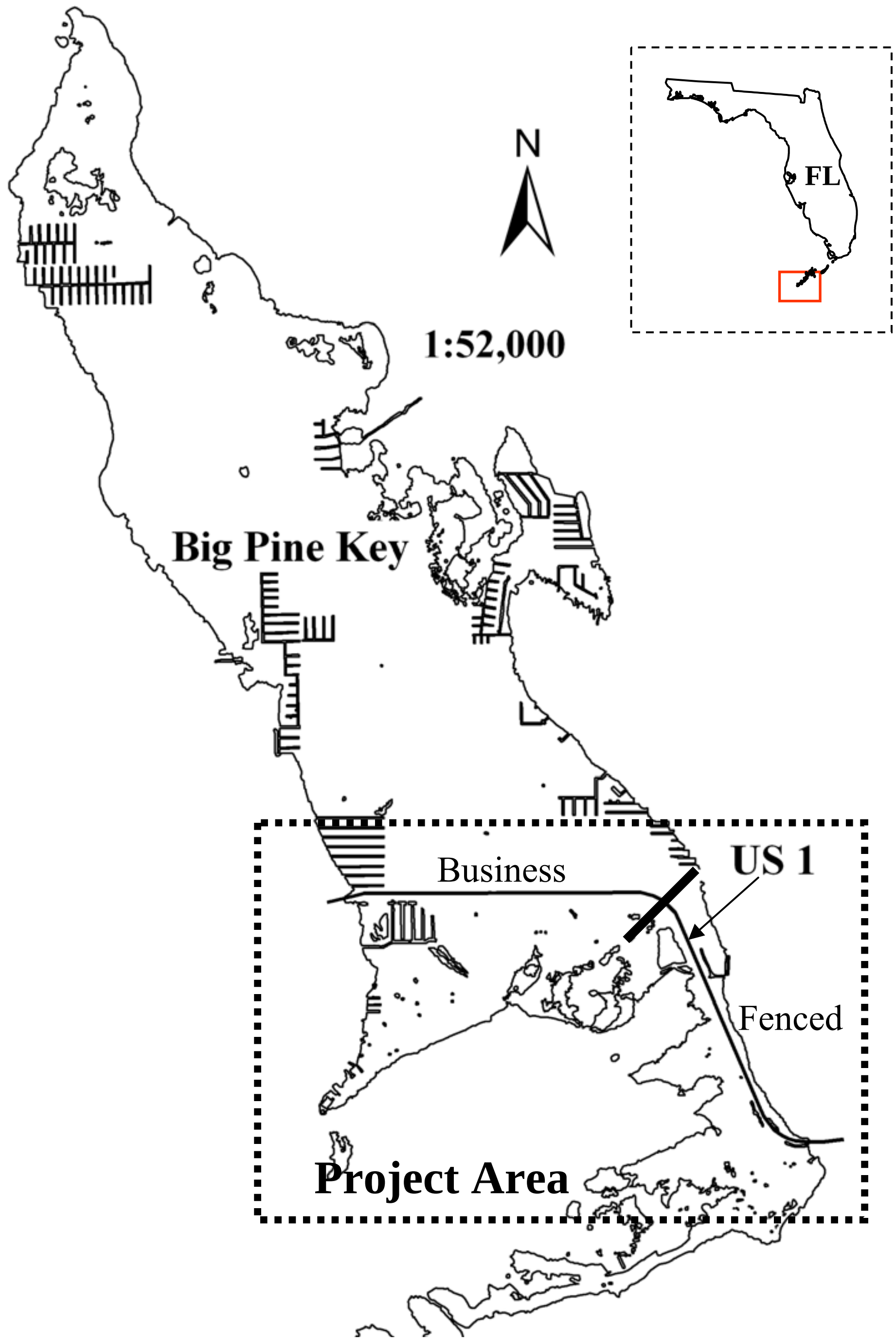

Figure 4.1. The study site (dashed line) including US 1 (5.6 km) divided into business (3.1 km) and fenced segments (2.6 km) on southern end of Big Pine Key, Monroe County, Florida.

In 1993, the Florida Department of Transportation (FDOT) began efforts to reduce Key deer mortality along the US 1 corridor on BPK. This proactive effort resulted in the formation of the Key Deer Ad-Hoc Committee in 1995 to evaluate viable solutions in reducing DVCs (Calvo 1996). The first set of recommendations included a system of fencing and deer guards on a 2.6-km segment of US 1, which were implemented in 2003 (hereafter called the fenced segment, Fig. 4.1). The project was successful in reducing annual Key deer mortality by 83-92% (Chapter II). Fencing the full-length of US 1 (5.6-km) was deemed impractical, however, because it included a business district where fencing could not be used (Calvo 1996, Lopez et al. 2003*a*, hereafter called the business segment, Fig. 4.1). The second set of recommendations from the study proposed non-structural roadway measures (e.g., increased lighting, signage, speed reduction) to reduce DVCs (Calvo 1996). The successful implementation of such measures, however, require an understanding of the relationship of DVCs to deer behavior and traffic patterns (Pojar et al. 1972, Pojar et al. 1975, Calvo 1996, Hughes et al. 1996, Gunson and Clevenger 2003, Knapp et al. 2004). Though Key deer mortality data have been collected since 1968 (Lopez et al. 2003*b*), factors that predict Key deer mortality, particularly DVCs, are poorly understood. Thus, the objective of my study was to determine factors that may predict DVCs, and once determined, to reduce them in areas where structural measures (e.g., fencing) were not feasible.

METHODS

Key deer occupy 20–25 islands within the boundaries of the National Key Deer Refuge (NKDR), with approximately 60% of the overall deer population on BPK (Lopez et al. 2004*a*; Fig. 4.1). My study was conducted on south BPK where US 1 (5.6 km, 2-lane highway) bisects the island. US 1 has an estimated annual average daily traffic volume of approximately 18,000 vehicles/day (FDOT data, Monroe County, 2004), though variable over the year with a peak during the tourist season (January–April). Maximum speed limits of 72 km/hr during the day and 56 km/hr at night are currently (2005) enforced on the BPK US 1 segment.

Deer Telemetry

Key deer were captured (female adult n =3, female yearling n =1) along the US 1 project area (≤250 m from roadway) between April 2003–August 2003 using portable drive nets (Silvy et al. 1975) and drop nets (Lopez et al. 1998). Prior to release, Key deer were equipped with Lotek GPS3300 GPS collars (Lotek Wireless Inc., Ontario, Canada) programmed to obtain hourly location; collars were retrieved 6 months later when collars automatically dropped off.

Following collar retrieval, location fixes were downloaded using Lotek GPS HOST (Version 1.930), and locations differentially corrected using Lotek N4 differential post-processing software (Version 1.2135). I calculated average hourly distances (m) for each individual deer using the animal movement extension (Version 2.2, Hooge and Eichenlaub 1999) in ArcView 3.3 (ESRI, Redland, California). An overall mean distance traveled (m/hr) was calculated for further analyses.

US 1 Traffic Levels

Since 1993, FDOT has collected hourly traffic data on US 1 at mile marker 25 on BPK (FDOT traffic unpublished data, Monroe County). I determined the average traffic volume (vehicles/hr) using 2003 traffic data.

Deer-Vehicle Collisions

Key deer mortality has been collected by NKDR biologists since 1966. Key deer mortalities were located based on direct sightings, reports from highway safety officers, and citizen reports. Data collected from deer mortalities included sex, age, cause of death, and location. For DVCs, collision data (e.g., estimated time of collision, time of deer death) also were collected. I calculated the average DVC by hour occurring along the US 1 corridor from 1995–1999. Deer-vehicle collisions with unconfirmed times of collision were excluded from my analyses.

Data Analysis

I used Spearman's rank correlations to determine whether hourly DVCs were associated with hourly mean distance traveled over the full circadian period and by light periods (night [2000–0400 hrs], sunrise/sunset [0500–0600/1800–1900 hrs], day [0700–1700 hrs]).

I also used rank correlations to determine the association of hourly US 1 vehicular traffic in predicting DVCs over the same periods (SPSS 2001). Comparisons for deer observations (mean distance traveled) were made using pooled estimates.

RESULTS

Deer Movements

A significant (P = 0.012) correlation (r = 0.505) was found between hourly DVCs and hourly deer movements. Hourly DVCs showed the same general pattern as hourly deer movements with both variables peaking during sunrise and sunset periods (mean sunrise = 0500–0600 hrs, mean sunset = 1800–1900 hrs; Fig. 4.2).

US 1 Traffic

No significant (r = 0.169, P = 0.430) relationship could be made between hourly US 1 traffic volume and hourly DVCs over the entire circadian period (Fig. 4.3). However, a significant (P = 0.012) correlation (r = 0.787) was found when hourly traffic and hourly DVCs during the night period (2000–0400 hrs) were compared.

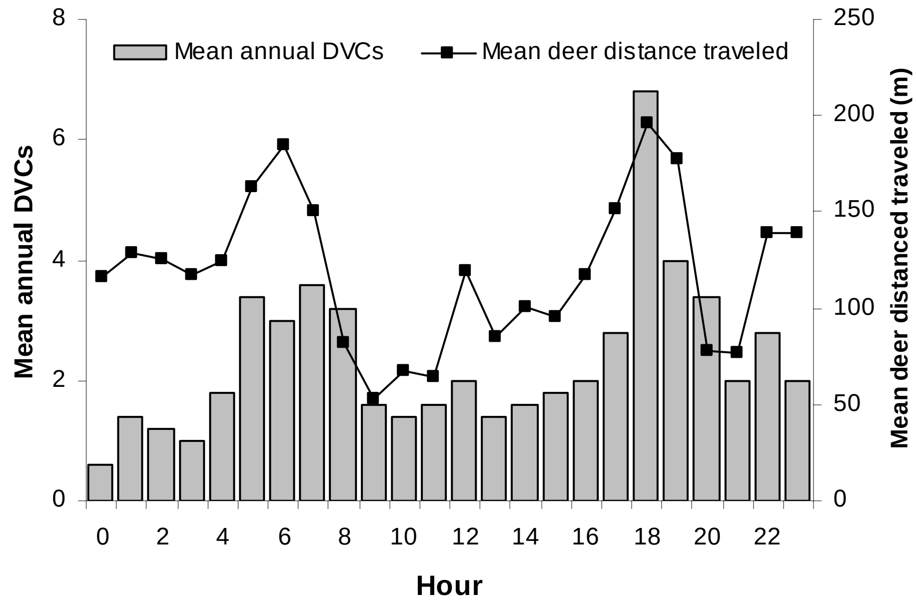

Figure 4.2. Relationship between mean hourly annual Key deer-vehicle collisions (1995–2000) and average hourly deer movement distances (m) on Big Pine Key, Florida.

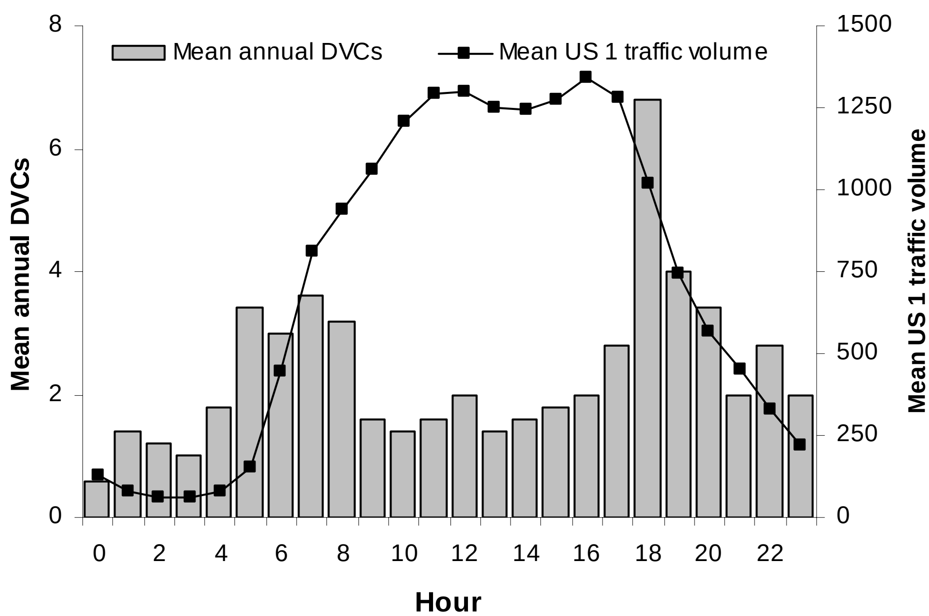

Figure 4.3. Relationship between mean hourly annual Key deer-vehicle collisions (1995–2000) and average hourly traffic volume (vehicles/hour) on US 1 on Big Pine Key, Florida.

DISCUSSION

Study results suggest that periods when Key deer were more active (i.e., traveled greater distances per hour) corresponded to high DVC periods. Currently, there has been little research relating hourly deer movements to hourly DVCs. However, my hourly results correspond to similar seasonal findings reported in previous studies for Key deer (Lopez et al. 2003*b*) and deer in other areas (Allen and McCullough 1976).

Comparison of traffic volume on US 1 to DVCs showed no strong relationship over the whole circadian period (Fig. 4.3). My results were similar to those reported for elk (*Cervus elaphus*) in the Central Canadian Rocky Mountains (Gunson and Clevenger 2003). In separating traffic volume on US 1 and DVCs into periods, however, a significant correlation was found for hourly traffic and DVCs during the night period (DVCs increased with increased traffic). Possible reasons for the observed association of traffic and DVCs during the night period may be the interaction of deer movements during this period (Fig. 4.2), and the understanding that deer habitat use varies from day to night periods (Montgomery 1963, Rouleau et al. 2002). For the latter, deer use of roads and more open areas (e.g., roadsides, yards, fields) at night might explain this increase. There also was evidence of an interaction effect of hourly traffic and deer movements during dawn and dusk periods (Fig. 4.4) though not significant.

MANAGEMENT IMPLICATIONS

Study results suggest DVCs on US 1 are associated with Key deer movements and traffic volume on US 1 depending on the time period. As a result, DVCs can be predicted and do occur during specific periods with the majority occurring during sunrise and sunset periods.

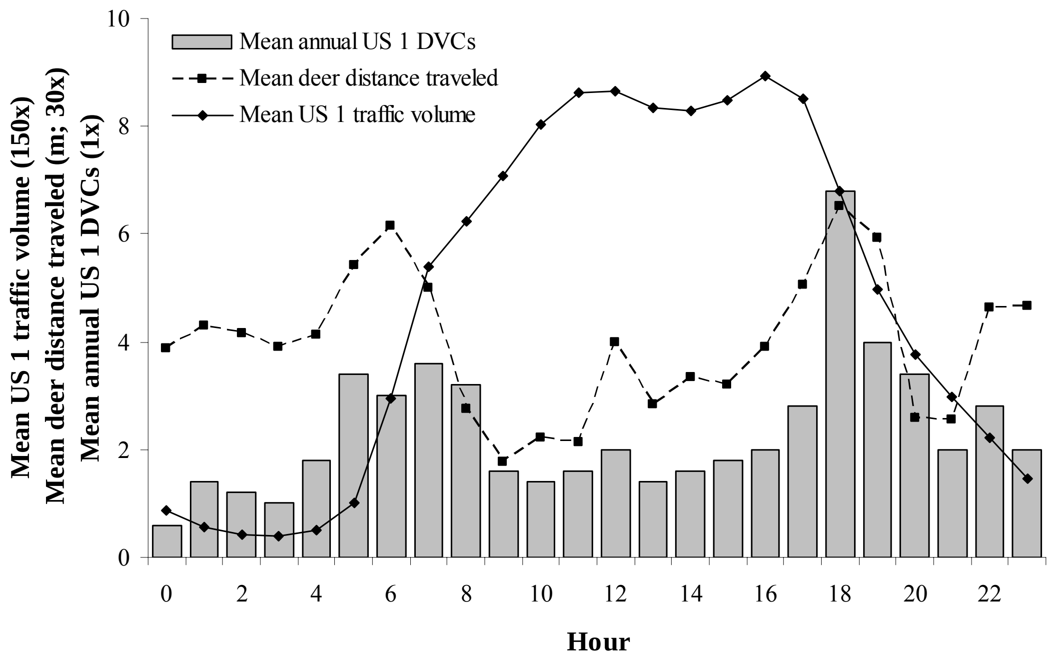

Figure 4.4. Relationship between mean hourly annual Key deer-vehicle collisions (1995–2000), average hourly deer movement distances (m), and average hourly traffic volume (vehicles/hour) on US 1, Big Pine Key, Florida. Deer movement distances and traffic volume on US 1 are at different scales to aid in comparison.

I propose DVC prevention strategies (e.g., speed reduction, speed monitoring, warning signage or lights) should focus on periods of both high deer movement (i.e, dusk, night, dawn) and high traffic volumes (i.e., dawn, dusk) to maximize their effectiveness. One example could be a time-based speed-reduction zone, similar to school speed zoning, which would go into effect during periods of high traffic and high deer movements regardless of the time of day (instead of traditional sunlight driven speed regulation [i.e., day-time-speed limit, night-time-speed limit]).

It should be noted that because both deer activity and traffic volume are involved in predicting when DVCs occur, the potential for periods of high DVCs other than sunrise and sunset is possible in other areas, seasons, and for other species. By understanding the location and circadian patterns of animal movement and traffic in other high-DVC areas, the best time periods to focus prevention strategies can be determined. Knowledge and information that improves the efficacy of non-structural DVC-prevention strategies are essential because the creation of physical barriers to prevent deer access to all roadways is not possible for all areas.

CHAPTER V

CONCLUSIONS

Post-project data indicate the US 1 fencing project has successfully reduced Key deer mortality along the fenced portion of US 1 by approximately 83–92% (from 12–24 [in 1996–2000] to 1 [in 2003]). Although overall US 1 deer-vehicle collisions did not change between periods due to deer-vehicle collision increases in the unfenced section, I hypothesize collisions in this section will decrease as deer become habituated to the project and their movements stabilize. Furthermore, although the cause for the increase in deer-vehicle collisions along the unfenced section of US 1 is uncertain, telemetry data indicated the increase in deer-vehicle collisions along this section may not be entirely due to the US 1 corridor project displacing deer over to the unfenced section.

Deer crossed the guards 6 times to enter the fenced segment which includes 4 experimental deer guards proposed by Peterson et al. (2003). Although pen trials found the deer guards to be 98% effective, the true effectiveness could not be assessed since I was unable to determine how many crossing attempts occurred during the pre- or post-fence periods. However, previous fencing studies have found that an acclimation period exists with wildlife fencing structures (Reed et al. 1975, Clevenger 1998, Hardy et al. 2003). Additionally, Key deer are known to have strong site and movement pattern fidelity (Lopez 2001). Thus, I propose the number of observed deer crossings may decrease as older deer acclimate to the location of crossings and as younger deer establish ranges with the fencing project in place.

Radiotelemetry data indicated the US 1 corridor project has the potential to maintain deer movements between surrounding Key deer habitats at a large scale. However, the camera data revealed that an acclimation period existed in the use of box underpasses by Key deer, and as Key deer became acclimated to the underpasses (about 6 months), underpass and corridor movements became similar. At a smaller (within-corridor) scale, radiotelemetry and camera data suggest that changes in movement patterns have occurred within the corridor as a result of highway improvements. Although full corridor crossings were of greatest concern, the potential for restricted movement within the corridor should not be ignored. Therefore, efforts should be made to improve and/or maintain movements within corridors by expanding and maintaining vegetative clearings along roadsides and reducing and/or eliminating other obstacles to movement (e.g., fill canals) when possible. Such management practices can ultimately influence overall corridor connectivity within the landscape for species of concern like the Florida Key deer.

Finally, study results suggest DVCs on US 1 are associated with Key deer movements, traffic volume on US 1, and time period. As a result, DVCs can be predicted and do occur during specific periods with the majority occurring during sunrise and sunset periods. As a result, I propose DVC prevention strategies (e.g., speed reduction, speed monitoring, warning signage or lights) should focus on periods of both high deer movement (i.e, dusk, night, dawn) and high traffic volumes (i.e., dawn, dusk) to maximize their effectiveness. One example could be a time-based speed-reduction zone, similar to school speed zoning, which would go into effect during periods of high traffic and high deer movements regardless of the time of day (instead of traditional sunlight driven speed regulation [i.e., day-time-speed limit, night-time-speed limit]).

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